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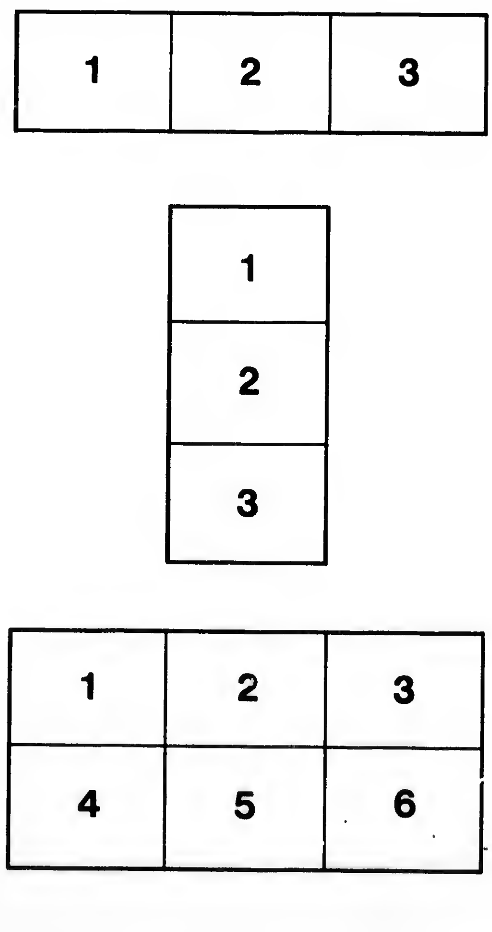

Changes of Level of the Great Lakes.

By G. K. GILBERT.

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CHANGES OF LEVEL OF THE GREAT LAKES.

THE following pages are devoted to the physical history of the lakes of the northern States. As avenues of commerce, as preserves of food fishes, as reservoirs of pure water, as resorts for the artist, the pleasure seeker, and the health seeker, their description is left to other pens. They are here treated only as physical features, the endeavor being to set forth their origin and the series of physical changes, past, present, and future, that constitute their history.

Rivers are the mortal enemies of lakes. The river that flows into a lake brings stones and sand and fine mud, and dropping these into the quiet water endeavors to fill the earth cup that holds it. The year's tribute of sediment may have as little apparent effect as the year's tribute of water, which quietly escapes to atmosphere and ocean; but the river is long of life and steadfast of purpose, and if years and centuries prove too short, it resolutely persists through geologic ages. The river that flows away from a lake constantly deepens its channel of escape, and thus attacks the lake's rampart at its weakest point. If the rampart is of loose earth, this is rolled and floated away bit by bit, and the work goes on merrily; if it is of firm rock, this is dissolved, and then the process is exceedingly slow. But time is long, and even by solution the rampart may be channeled to its base and the whole lake drained away.

Nevertheless, in spite of this warfare of extermination, waged in all lands and through all time, there continue to be lakes, and so there must be in nature lake-producing as well as lake-destroying agencies. There are indeed many such, but a few only need be appealed to to explain the great majority of lakes, and the chief are upheaval and glaciation.

Some parts of the earth's surface are known to be rising and others to be sinking. Usually such changes are of imperceptible slowness, but occasionally there is a sudden movement of a few feet, involving rupture of rocks and an earthquake. Similar movements have abounded through past ages of the earth, and to them are due not only mountains and plateaus, but continents and ocean beds. This great natural process of uplift and downthrow tends to produce lake basins, and, as we have seen, its tendency is opposed by the great natural process of erosion and deposition by rivers. The two are so nearly balanced that the scale is thrown to one side or the other by the accident of climate. Where much rain falls the rivers are powerful and prevail, sawing gorges through ridges as fast as they rise, building up the floors of valleys as fast as they sink. Where little rain falls the streams are weak, and the displacement of the earth's crust shapes the land into lake basins. Where the least rain falls the basins are many, but the lakes are ephemeral, created by the storm and dissipated by the sunshine. Great Salt Lake, Utah and Humboldt Lakes, and a score of others in our arid belt lie in valleys shaped by crustal displacement.

A glacier is aptly called a river of ice. Like a river of water it has an upper surface sloping continuously from source to goal, and like a river of water it rests on an uneven bed of its own shaping. When an aqueous river is suddenly deprived of its supply of water, there remain along its channel a series of pools recording the inequalities of erosion. When a great glacier is melted away the inequalities of its erosion are recorded in a chain of lakes. Moreover, much of the material ground and torn by the glacier from its bed is carried forward in the ice and dropped in a long heap where the ice melts, constituting a moraine. If the final melting is gradual, a series of moraines partitions the valley, creating lake basins. While it is building a moraine, the ice front advances and retreats in response to small changes in climate, so that the dropping of detritus is irregular, and the surface of the moraine is made billowy, abounding in small lake basins. Thus from glacial erosion there arise rock-basin lakes, and from glacial deposition of detritus there arise moraine-dammed lakes and moraine lakes.

In that wonderful geologic winter known as the Age of Ice, the annual snowfall on the northern part of our continent was so great and the annual melting was so small that the snow accumulated year by year, and became cemented into a continuous, deep, and ever-growing sheet of ice. As the depth of the sheet increased the pressure of its own weight became finally insupportable, and there was relief by horizontal flow, the margin moving outward to a region of warmer climate, where it was melted. It was, in fact, a vast glacier, so vast that the figure of speech embodied in the title "river of ice" becomes here inapt. Instead of flowing from a mountain down a sloping valley, it flowed radially from a central plateau of ice, with little regard for the slopes of the land over which it passed. We do not yet know the center of dispersion, but the ice entered our land as an invader from Canada. The border States from Maine to Minnesota were overrun, and most of the land north of the Ohio and Missouri Rivers. Twice the van was pushed far into the domain of the sun, and twice it was compelled to retreat; but when the sun finally surveyed its reconquered territory, the land was no longer simply graven with a tracery of rivers; it sparkled with the sheen of innumerable lakes.

Wherever the ice moved it swept forward the soil and all other loose material, and with them scoured the firm rock beneath, producing a polished surface of peculiar character, with many scratches and furrows parallel to the direction of motion. In some regions it did little more than this, but elsewhere it was a powerful agent of erosion, scooping out great hollows from the solid rock. For some reason not clearly understood the erosion was greatest along a zone parallel to the margin and a few hundred miles back from it, and here were formed the basins not only of the Laurentian lakes from Ontario to Superior, but of Winnipeg, Athabasca, Great Slave, and Great Bear Lakes. Within this zone of greater erosion the points of greatest erosion were determined chiefly by the pre-glacial shape of the surface. Where the land was high the overriding ice sheet was relatively thin, its motion correspondingly slow, its pressure slight, and its erosion unimportant. Where the land was low the deeper ice stream flowed faster, pressed harder on its bed, and eroded rapidly. How deep the original valleys were cannot be told, for the details of the old topography have been ground away, but

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we may be sure that they were shallow as compared to the existing troughs. The depths of Lakes Michigan, Superior, and Ontario reach from three hundred to five hundred feet below the level of the ocean, and their origin cannot be referred to stream erosion alone without incredible assumptions as to continental elevation.

Between the Great Lakes and over the country south of them are spread moraines and other deposits of ice-transported *débris*. They vary greatly in composition, structure, and topographic form, but have this in common, that their material differs in kind from the solid rock immediately beneath it, having been brought from more northerly points. Collectively they are called the Drift, and they dominate the surface, often concealing the rock for scores of miles. The typical morainic drift has a hummocky surface, abounding in small lake basins called "kettles;" other varieties undulate more gently, and harbor broader but shallow lakes; and elsewhere the surface is smooth and completely drained. Over large districts, especially north of the Great Lakes, the drift is scant and irregularly spread upon an uneven rock surface, and there lakes are especially abundant. Many of them lie in rock basins, but the most are partly contained by walls of drift.

The Great Lakes, with the possible exception of Erie, all occupy rock basins, that is to say, they lie in hollows having continuous rims of solid rock; but these rims are in places coped by accumulations of drift in such way as to increase the depths and areas of the lakes and control to some extent the direction of their outflow. It is probable that the surplus waters of Superior and Ontario escape over the lowest points of their rocky rims, but if the drift were removed at the south end of Michigan the lake would find a lower outlet and become tributary to the Mississippi. The removal of drift between Huron and Erie would probably render them confluent, as Huron and Michigan now are. The removal of drift between Erie and Ontario would greatly reduce the upper lake, or possibly drain it completely, and would make it tributary to the lower at Hamilton, Canada, instead of at Fort Niagara.

As soon as the ice was gone running water began a work of reclamation, washing the earth from the steeper slopes down into the lakelets, and cutting down their outlets until they became so shallow that vegetation could take up the work and fill them to the top with peat. Half of the moraine lakes have been thus converted into marshes, and through extensive districts in Ohio, Indiana, and Illinois only the marshes, and the deposits of peat and marl where marshes have been drained, remain to show how numerous were the lakes. The drift-dammed lakes are better preserved, partly because in their region there is less loose *débris* with which to fill them, partly because their outflow is often across resistant rock. Of progress toward the destruction of the Great Lakes there will be occasion to speak in another connection.

But the story of the lakes is not completely told by explaining the origin of their basins; there is also a history of their development as water bodies. During the period of greatest ice expansion the hydrographic basin of the Great Lakes and the valley of the St. Lawrence were not merely filled but overpassed, so that the rivers generated on the glacier in summer fell from its southern edge beyond the rim of the Great-Lake basin, and flowed to the Missouri, the Mississippi, the Ohio, the Susquehanna, and the Delaware. As encroaching heat gradually reduced the limits of the ice, its retreating margin reached and passed the basin rim at various points, and there accumulated between the water parting and the ice wall a series of glacial lakes, fed by the melting ice and discharging southward across the passes of the great divide. The precise order of events has not been made out, but there was a time when the western part of the Superior basin contained a lake discharging to the Mississippi River by way of the St. Croix, there was a time when the southern part of the Michigan basin held a lake discharging to the Mississippi by way of the Des Plaines and the Illinois, and there was a time when a lake, occupying the western half of the Erie basin and covering the Maumee valley, overflowed at Fort Wayne to the Wabash River, and thus sent its water to the Ohio. At a later stage a single sheet of water covered the southern part of the Huron basin and all the Erie, and encroached slightly on the Ontario. Then the ice retreated from all the

Ontario basin, but remained in the valley of the St. Lawrence, pressing against the Adirondack uplands. By this retreat Erie and Ontario were differentiated, and the Niagara River came into existence; but, as we shall see, the map was far from assuming its present aspect. The water of Ontario, having no escape by way of the St. Lawrence valley, sought the lowest pass south of the Adirondacks, finding it where the engineers of the Erie Canal afterward found it, and overflowing at Rome to the Mohawk River. This discharge was maintained for a long period, giving the waves time to construct massive beaches and carve broad terraces which still endure. They have been traced all about the basin, except, of course, on the northeast, where the waves broke vainly on an unrecording wall of ice. The "Ridge Road" from Lewiston to Sodus follows the crest of one of these beaches; a railway from Richland to Watertown has found easy grades along the base of another.

It is impossible, within the limits of a magazine article, to assemble or even cite the documents on which this historical sketch is founded; but it may be stated, in brief, that they consist of deserted shore lines, deserted river channels, muddy lake sediments enveloping bowlders dropped from icebergs, and old stream valleys flooded by encroaching lakes. One of the most important bodies of evidence is educed by measuring the height of the same shore line at different points. Originally the shores were horizontal, of course, each at its own level, but they are not so now. They rise toward the north, and, less rapidly, toward the east; and we learn thereby that when they were made the face of the land had a different attitude, being lower at the north and east, as though depressed by the weight of the ice.

At the epoch of the separation of Erie and Ontario the northward tilting of the land exceeded three hundred feet in the length of Ontario, and amounted to half as much in the length of Erie. The northeastern end of Erie being fixed in height, as it still is, by the outlet at Buffalo, the plane of its level surface cut the western slopes of the basin at a lower point, and the lake was smaller. It was, indeed, only one-third as long as now, and its water surface but one-fifth as great. The sites of Toledo and Cleveland were far inland, and the Bass Islands were smooth hills in the Maumee valley. Finally the blockade was raised in the St. Lawrence valley, the outlet of Ontario was shifted from Rome to the Thousand Islands, and its water level was drawn down five hundred feet. During the Rome epoch of its history Ontario's area was 60 per cent. greater than now; it began the Thousand-Island epoch with an area 30 per cent. smaller than now.

While yet the glacier was present and the navy of Ontario was a fleet of icebergs, the depressed land at the north had begun to rise again. When the glacier was quite gone the reflux was rapid, the land soon reached a more stable position, and the lakes acquired their present dimensions. Had the oscillation received no check, our hydrography and avenues of commerce might have been very different; a further tilting of the land to the extent of three inches in each mile would send a great river from Chicago to the Mississippi, reverse the current in the Detroit, stop Niagara Falls, and rob the upper St. Lawrence of seven-eighths of its water.

Has the oscillation ceased? Is Niagara destined to run dry? These are questions hard to answer for the remote future into which science fain would peer, but less difficult as concerns those few generations of posterity to which our ambitions and sympathies extend. It is one of the inductions of geology that absolute stability is a myth, and all parts of the earth's crust continually undergo changes of level. There is no reason to believe that the lake district is an exception to this law, but whatever movements may be there in progress are so slow that they have not been detected, and their tendency is unknown. In our use of the lake harbors we have observed no changes requiring earth movements for their explanation, and this negative testimony, so far as it goes, shows present stability. That which the waves have done to the present coasts, in the cutting back of cliffs and the building of spits, is a work of many centuries, during which the water level must have remained nearly constant; and the practical stability thus shown for the immediate past is a guarantee for the immediate future.

There is no question that changes of other kinds are in progress. Storm waves and storm currents are eating away the coasts and spreading the fine *débris* over the lake bottoms, where it mingles with the muddy tribute brought by flooded rivers; the St. Clair River is feebly scouring its channel and building its delta; the Falls of Niagara are gnawing back toward Lake Erie at the rate of four or five hundred feet in a century; and with infinite slowness the Ste. Marie, Detroit, and St. Lawrence Rivers are deepening their rocky beds. In a future geologic age all the lakes that survive the erosion of outlets will have succumbed to filling by alluvial mud, and the reign of running water will once more be established.

But the lake basins are so capacious that we become aware of their slow filling only by observing the discoloration of the water in times of freshet and of storm. The scour of the St. Clair can do no more than reduce the level of Lake Huron to that of Lake St. Clair, a difference of two or three feet; and as the reduction proceeds, its rate, now exceedingly slow, must continually diminish. If the recession of Niagara Falls were to continue at its present rate, Lake Erie would be tapped in two hundred centuries; but the rate is determined by the geologic structure, and that structure changes between Goat Island and Buffalo in such a way as to retard the work of erosion.

All these processes are too slow to affect our hopes or fears concerning the immediate future, and for our posterity in the year 20,000 we have no solicitude. The men who shall watch the draining of Lake Erie—or who, perchance, shall find it worth their while to prevent it—will as far surpass us in powers and resources as we surpass the men who watched the lake's creation. For all practical purposes our inland seas are permanent and their basins stable. The only modifications that affect our economy are those wrought by the waves upon their coasts.

Nevertheless, their stability is sometimes called in question. Their levels are not absolutely constant, but oscillate under various influences about a mean position, and when they are unusually low the "oldest inhabitant" is interviewed, and is reported to declare that the like was never seen before. Then some theory of permanent change is promulgated and the sensation has its day. While yet the newspaper discussion of the recent lowering of water levels is fresh in memory it will not be amiss to recite briefly the conditions on which such changes depend.

About each of the lakes is a district of land draining toward it. A portion of the rain and snow falling upon this land is returned to the atmosphere by evaporation from the soil, and a larger portion is returned by evaporation from the surfaces of plants. The remainder flows to the lake and tends to raise its level. Its level is also raised by the rain and snow falling upon it. On the other hand, its level is lowered by evaporation, and is lowered by the discharge through the outflowing river. In the long run the supply from inflow and rain is balanced by the loss through evaporation and outflow, and so in a general way the lake altitude is constant; but in detail it is inconstant, oscillating about its average position.

The additions to the lake by rain are not uniform through the year, but are usually greater in summer. The additions from tributary streams are still less uniform, being smallest in winter, when precipitation takes the form of snow, and largest in spring, while the snows are melting. The loss from evaporation is likewise unequal, varying with the temperatures of air and water, with the dryness of the air, and with the velocity of the wind, and being usually greatest in summer and autumn. Thus supply and loss are not balanced in detail; at some seasons there is a net gain and the lake surface rises, at others there is a net loss and it falls, and the rise and fall together constitute an annual oscillation.

A second difference depends on the variation of weather from year to year. In some years more rain and snow fall, in others less, and there is a similar fluctuation in the atmospheric conditions affecting evaporation. When the rainfall is greater than usual or the evaporation less, the lake rises; when the rainfall is small or the evaporation great, the lake falls. A succession of wet years produces exceptionally high water, a succession of dry years extremely low water. But there is a limit to such cumulative effects, for when the lake is high its outflow is more rapid than when it is low, and an automatic check is thus furnished.

Thirty years ago Colonel Charles Whittlesey compiled all available data regarding the fluctuations of the lakes, and was able to publish an account of the more important changes of the lower lakes between the years 1838 and 1857, together with a few data concerning exceptional phenomena in earlier years. In 1859 the United States engineers began systematic gauge-readings, and their work is still continued. The following table is based on their records, and shows the ordinary range of fluctuations. Michigan and Huron are here treated as one lake because their waters communicate freely through a strait.

Lake.	Period of record.	Usual date of		Mean annual range. (Feet.)	Extreme range for whole period. (Feet.)
		highest stage.	lowest stage.		
Superior.........	1871–87	August.	April.	1.3	3.0
Michigan-Huron..	1860–87	July or Aug.	Jan. or Feb.	1.2	3.9
Erie	" "	June or July.	" "	1.6	3.5
Ontario..........	" "	June.	" "	1.8	4.7

The highest water known occurred in 1838, when Michigan-Huron rose 26 inches above ordinary high stage, and Erie and Ontario 18 inches. The lowest water known was in 1819, when Erie fell about 3½ feet below its usual plane.

The present low water is the sequel of last summer's drouth. The Signal-Service records indicated that the lake region received in the year 1887 only about 26 inches of rainfall instead of its usual quota of 33 inches. If the evaporation and the discharge remained constant, the lakes should fall 7 inches by reason of the defect of aqueous precipitation on their surfaces, and about as much more by reason of the defect of inflow; but, taking the average for all the lakes, the actual fall from the low stage of 1887 to the low stage of 1888 has been only 7 inches. The variation of rainfall was, therefore, great enough to account for the variation of lake surface. That it was more than sufficient is probably explained by the coolness of the autumn, which tended to diminish evaporation. In Superior the low water of last February reached 5 inches below the level of the average low stage, a depression exceeded but twice in seventeen years.

In 1879 and 1880 the water was 3 inches lower. In Ontario, the lake most affected, the low water of 1888 was 6 inches below the average, but this record has been exceeded six times in the last twenty-eight years. 1868 marks 10 inches below, 1872 16 inches, 1873 14 inches, 1875 (February) 13 inches, 1875 (December) 7 inches, and 1881 11 inches. In Michigan-Huron the recent low water was but 2 inches below the average, and in Erie but one inch. If our inland commerce has need to be assured of the continued fidelity of its "unsubsidized ally," it can find comfort in the contemplation of these figures.

The oscillations described affect an entire lake uniformly. There are others that affect its parts differently, the water rising in one place while falling in another. The most powerful cause of such displacement of level is the wind, which, driving the surface water before it, heaps it up against the lee shore; and the greatest effects are seen in Erie, whose shallowness interferes with the adjustment of levels by means of a return current beneath. A gale blowing in the direction of the lake's length has been known to raise the level seven or eight feet at one end and depress it an equal amount at the other.

Oscillations of a second kind are caused by inequalities and variations of atmospheric pressure. When the air presses unequally on different parts of a lake an equilibrium is reached by a depression of the water surface under the heavier column and its elevation under the lighter. If the air pressures are rapidly shifted, as in the case of thunder-storms and tornadoes, rhythmic undulations are produced analogous to those from the dropping of a pebble in still water, and traveling like them to remote shores. The rhythmic period is usually measured in minutes and the height of the undulation in inches, but waves of this class sometimes equal the largest generated by wind. The passage over Lake Michigan of a broad wave of barometric change sets the water to swaying from side to side as we sometimes see it in a hand basin; but the greater body has a longer period, advancing and receding only eleven times in twenty-four hours.

Third and last are the tides, which ebb and flow in lunar and solar cycles as regularly here as on the ocean, but are unheeded by the navigator. The highest determined spring tide rises about 3 inches, and the average height of tide on the shores of the larger lakes is probably not more than one inch.

And so these lakes of ours, that seem to ordinary observation as enduring as the earth and yet as fickle as the weather, are to the trained imagination of science both ephemeral and constant. The geologist looks backward to the time when they were not, and forward to the time when they will no longer be; talks of their birth, growth, decline, and death, and, comparing their span of life with the earth's, declares them evanescent. The physical geographer, analyzing the motions of the water, refers them to the attractions of celestial bodies, the pressures of air, the friction of winds, the varying dryness of the atmosphere, and the varying rain, and assigning each fluctuation to its appropriate cause, lays bare a fundamental constancy to which the navigator and the statesman may safely pin their faith.

G. K. GILBERT.